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Fusion Energy
Plasma Material Interaction as Hot Topic

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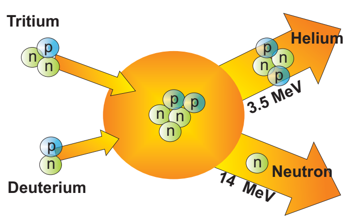
In a world where new solutions for energy transformation are needed, fusion might be a safe and world wide available solution. The fuel needed can be gained from water (deuterium) and stones (lithium, which needs to be bred to tritium). The noble gas helium is the fusion product, the so called helium ash. Fusion works in a hot plasm, where electrons and ions exist separately and do not form atoms any more.

Therefore, it is crucial to control the plasma wall interaction (PWI) of the hot plasma with the wall in order to achieve long lifetimes, i.e. in future fusion reactors.
This contribution focuses on the PWI in a three dimensional (3D) geometry.

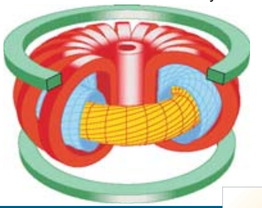
Fusion reaction:



Thermo nuclear fusion in reactors needs high temperatures. The fusion of tritium and deuterium nuclei has the most effective cross section at temperatures around 100 Mio K. Here, the atoms are fully ionized, the nuclei and electrons form a thermo nuclear plasma.

The Tokamak:

A tokamak is based on an electric transformer with the plasma being the secondary winding. The ions and electrons are magnetically confined. They are forced to follow helical field lines, formed by poloidal and toroidal magnetic field components.
Fusion in tokamaks is the most advanced approach in energy transformation. A second line of devices are the stellarators, which are not based on the el. transformer principle (world largest stellarator is under construction in Germany: Wendelstein-7X).



In red the coils for the main toroidal magnetic field component are depicted.

Due to the plasma current a poloidal magnetic field arises.

Both magnetic components form the helical magnetic field lines.

Plasma wall interaction (PWI):

Direct contact of plasma and first wall has to be controlled and limited, especially regarding the high heat loads.

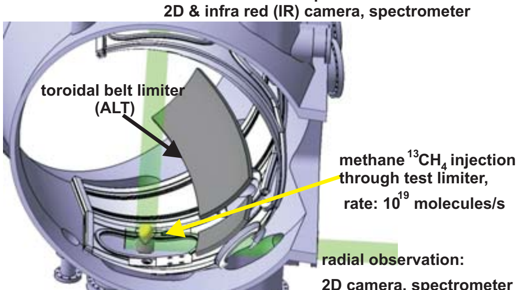
The plasma with good energy and particle confinement has steep gradients in density and temperatures at its boundary. This leads to instabilities and high transient heat loads to the wall, which have to be avoided.

Here, one possible solution is the applictaion of resonant magnetic perturbation (RMP) fields. These fields lead to a stochastisation of magnetic field lines. Therefore the flux surfaces in the plasma edge break up, forming a new 3D boundary.

Up to now the consequences of this 3D boundary concerning the PWI are not known. Hence, the challenge is the understanding of material erosion, transport, and deposition in the 3D structure.

Experiments on material erosion, migration, and deposition at the tokamak TEXTOR

observation from top:
2D & infra red (IR) camera, spectrometer

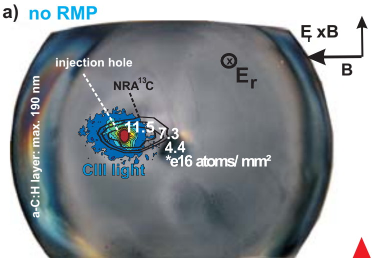


2 graphite (polished EK 98) test limiters exposed:
- **11 unperturbed plasma discharges**
- **11 plasma discharges with applied RMP**

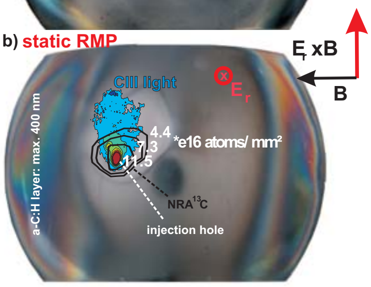
+ one extra limiter, 11 discharges sweeped RMP

Typical E_r values [2]: **no RMP < 1 kV/m**
static RMP ~ 3-4 kV/m

a) no RMP



b) static RMP



- **light emission flag of ions tilts in E_rxB drift direction**
- **^{13}C re-deposition pattern: re-deposition efficiency 7% in both cases**
- **a-C:H layers 2x thicker in RMP case [3]**

Safety issues:
Activated wall material, due to neutron impact, has a short cool down time and can be recycled after about 100 years.
Licence regulations limit the amount of tritium inventory to minimize radiation hazards in case of leakage.

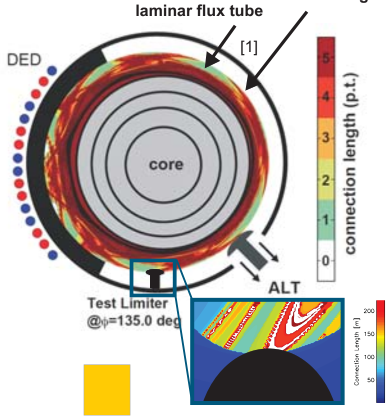
Modeling of experimental results

codes used:

GOURDON Code [4]
Field line tracing code, without plasma response. Here a Poincaré plot and connection lengths are shown.

ERO Code [5]
3D monte carlo code with full kinetic model of impurities and wall

EMC3-EIRENE [6]
EMC3: solves set of Braginskii fluid equations (particle, energy and momentum)
EIRENE: 3D kinetic neutral transport code



ITER
The next step fusion device

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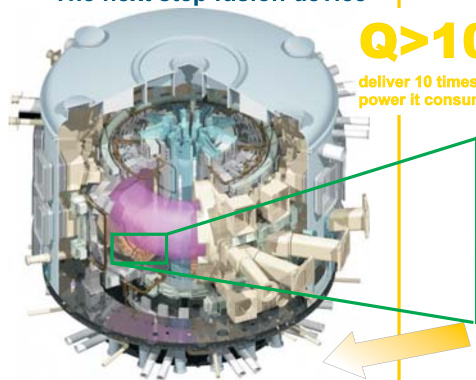

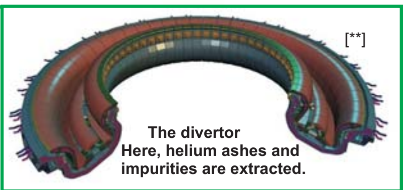

A cut-away view of the ITER tokamak, revealing the donut-shaped plasma inside of the vacuum vessel.
- 1,400 m^3 vacuum vessel
- 11.8 T magnetig field (5 T at plasma center), coils super conducting (earth mag. field ~ 60 mT)

Aim: First quasi stationary fusion plasma with Q=10, toroidal magnetic field B_T= 5.3 T, a plasma current I_p=15MA, and a density n= 10^{20} m^3.

Extrapolation to ITER divertor:
- **is the divertor integrity endangered by 3D boundary structure?**
- **if it is, can sweeping of perturbation currents help prevent damages?**

Preliminary Results

The effects of a 3D plasma boundary onto the material erosion, transport and deposition are analyzed. For this, two plasma scenarios have been investigated, one without RMPs, and hence with a 2D symmetry, and one with applied RMPs, leading to a 3D structure.

Observed changes from no RMP to RMP:
- **local modulation of plasma parameters**
- **90° tilt of light emission flag**
- **re-deposited ^{13}C mixture of neutral and ion-deposition**
- **enhanced co-deposited deuterium in far scrape of layer**

Explanation:

In stochastic fingers the material migration is dominated by a higher E_rxB drift.

The kinetic movement of neutrons and ions in the 3D boundary determines the re-deposition.

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[**] www.iter.org, Sept. 2012
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